MTIE AND TDEV ANALYSIS OF UNEVENLY SPACED TIME SERIES DATA AND ITS APPLICATION TO TELECOMMUNICATIONS SYNCHRONIZATION MEASUREMENTS

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Abstract

In this work, we investigated the effect of uneven data spacing on the computations of MTIE and TDEV. We evaluated MTIE and TDEV with unevenly spaced data having the five different power-law noise types. Each simulated data set had 3600 evenly spaced data points spaced one second apart. In the next step, we removed data points for each file according to the parameter p. Each data point in a file was removed with probability p and not removed with probability $(1-p)$. And for the unevenly spaced data files, the average spacing was recomputed. Then we computed MTIE and TDEV for these data files with different p values. The results show that the difference among the performance of various p values is not significant when the observation time τ is larger than 100 seconds. In addition, the discrepancy between the computation results of evenly and slightly unevenly (p is small) spaced data files can be negligible. It reveals that we can ignore the effect of slightly unevenly spaced data on the computations of MTIE and TDEV. Based on the results, one can employ a simple model to conduct the network synchronization measurement. In other words, in the telecommunications synchronization measurement, a clock recovery device that recovers the timing signal from the data bits is no longer required. We can input the network data signal to the time interval counter (TIC) directly. The measured data are often not evenly spaced, since the data bits of "1" and "0" are not distributed regularly. But based on the previous results, this novel measurement model can still be validated.

INTRODUCTION

Network synchronization has played a central role in telecommunications networks since the introduction of digital exchanges. In digital communication systems, the variations of the significant instants of a digital signal from their ideal position in time are called jitter or wander. Jitter is usually induced in the regenerators or multiplexers where bit stuffing or pointer justification events can occur, and may increase the bit error rate in the receiving end. For guarantee of network synchronization quality, ITU-T has

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enacted several measurement parameters in G.810 **[1]** and the jitter and wander specifications in G.823 **[2]**, G.824 **[3]**, O.171 **[4]**, and O.172 **[5]** for equipment testing and telecommunications measurement. In this paper, we will only focus our discussion on the MTIE and TDEV, which are important parameters for characterizing the wander. The definitions of MTIE and TDEV are as follows.

$$MTIE(\tau) = \max_{j=1}^{N-n}\left\{\max_{i=j}^{n+j}(x_i) - \min_{i=j}^{n+j}(x_i)\right\}, \tag{1}$$

$$TDEV(\tau) = \sqrt{\frac{1}{6n^2(N-3n+1)}\sum_{j=1}^{N-3n+1}\left(\sum_{i=j}^{n+j-1}(x_{i+2n} - 2x_{i+n} + x_i)\right)^2}\ , \tag{2}$$

where $\tau = n\tau_0$ is the observation interval and τ_0 is the sampling interval of the TIC. The discrete set of samples x_i is the *i*-th sample from the measurement starting time. The MTIE observation interval $\tau = n\tau_0$, specified in ITU-T standards, spans from 0.1 s to 10^3 s, or even wider from milliseconds up to 10^5 s.

According to the MTIE and TDEV definitions in **[1]**, the samples are assumed to be evenly spaced. However, all the samples are often not separated evenly in actuality, due to the instrumental errors, noise interference, or data loss. In such cases, is the MTIE or TDEV computation still correct or reliable? In this paper, we will investigate the effect of uneven data spacing on the computations of MTIE and TDEV.

METHODS OF EVALUATION

There are two methods frequently used **[6]** for doing with the unevenly spaced data analysis. One is the Linear Interpolation scheme that interpolates the missing data to form the complete data set. The other one is called as the Average Sampling Interval scheme. It assumes the data are evenly spaced, but the sampling interval should be re-averaged according to the number of data actually obtained. For these two approaches, are the calculated results of MTIE and TDEV still correct or reliable? Intuitively, the Linear Interpolation scheme seems more reasonable than the Average Sampling Interval one. However, in real measurements, the spaces between adjacent data points can be different even though no data loss exists. In order to investigate the effects on the performance of MTIE and TDEV resulting from the data space deviation, we will only discuss the Average Sampling Interval scheme hereafter.

The purpose of this paper is to analyze the performance of MTIE and TDEV for unevenly spaced data, and make a comparison with that of evenly spaced data. First, we simulate five types phase noise data. These five noise types are FLFM (Flicker Frequency Modulation), FLPM (Flicker Phase Modulation), RWFM (Random Walk Frequency Modulation), WHFM (White Frequency Modulation), and WHPM (White Phase Modulation). Each simulated data set has 3600 points, and these data points are assumed to be evenly spaced with constant sampling interval 1 sec. Secondly, according to the parameter p, each data point will be removed with probability p and not removed with probability $(1-p)$. After this removing process, the residual data become the unevenly spaced data. In order to analyze such an unevenly spaced data set, we adopt the Average Sampling Interval scheme as described above. The sampling interval is re-averaged according to the number of the residual data points. For example, if the number of the remaining data points is N, the new average sampling interval becomes $3600/N$.

NUMERICAL RESULTS

Figures 1 to 10 show the results of MTIE and TDEV obtained for the simulated five noise types. The fast algorithms for MTIE and TDEV computations presented in **[7]** and **[8]** are used. The noise parameter in the simulation is set to be 1×10^{-6} at $\tau=1$ sec for the Allan deviation. In each figure, there are three curves. Curve 1 is for evenly spaced data that is equivalent to the case $p=0$. Curve 2 and Curve 3 are for unevenly spaced data with $p=0.2$ and $p=0.5$, respectively. It is obvious that the larger the parameter p is, the more unevenly the data are spaced. That is, the deviation of the space intervals between adjacent data points increases when p increases.

Figures 1 to 5 indicate the results of log (MTIE) versus log (τ). One should note that MTIE is a non-decreasing function of the observation time τ. For all noise types, the results of MTIE show that the difference among the cases $p=0$, $p=0.2$, and $p=0.5$ is not significant when τ is larger than 100 seconds. Figures 6 to 10 represent the performance of log (TDEV) versus log (τ). The behavior of TDEV versus the observation time τ is irregular for different noise types. However, the performance difference between the evenly and unevenly spaced data is also negligible, especially when the observation time is larger than 100 seconds. One can observe that the behaviors of TDEV versus τ under different noise types are almost consistent with the results presented in **[6]**. In addition, one can also conclude that the performance deviation between the case $p=0$ and the case with small *p* value is obviously negligible for both MTIE and TDEV.

THE SYSTEM ARCHITECTURE OF TELECOMMUNICATIONS SYNCHRONIZATION MEASUREMENT

The conventional system architecture of telecommunications synchronization measurement can be shown as in Figure 11. It usually consists of a Time Interval Counter (TIC), a Clock Recovery Circuit (CRC), an Oscillator (Reference Frequency Source), and a Computer. The telecom signal inputs to the CRC and then a sinusoidal timing signal outputs to the TIC. Next, the phase error between the extracted timing signal and the reference frequency signal is measured and outputs to the computer. With the measurement software installed in the computer, we can easily obtain the synchronization performance, such as MTIE and TDEV, of the telecommunications networks. However, for different speed telecom signals, different CRC signal interfaces should be employed. It is somewhat inconvenient for doing measurement. Hence, in the novel architecture we suggest that one can use the software to implement the function of CRC, so that the hardware CRC is no more required. In other words, we can input the telecom data signal to the TIC directly without a CRC interface in the new system architecture. In order to explain this idea, we describe the concept of phase error measurement shortly in the following. We assume the telecom data signal to be $s(t)$ and

$$s(t)=a(t)\sin\phi(t), \tag{3}$$

where $a(t)\in\{0,1\}$ is the data and the phase $\phi(t)$ can be expressed as $\phi(t)=\omega_0 t+\theta(t)$. At the

trigger instant t_i, the phase is $\phi(t_i) = \omega_0 t_i + \theta(t_i) = n_i \cdot 2\pi$. The phase error between $\phi(t_i)$ and the reference signal is denoted as $\theta(t_i)$, which can be written as

$$\theta(t_i) = n_i \times 2\pi - \omega_0 t_i = \omega_0 (n_i T_0 - t_i), \tag{4}$$

where $f_0 = \dfrac{\omega_0}{2\pi} = 1/T_0$ is the standard reference frequency. Based on the phase error $\theta(t_i)$, one can derive the Time Interval Error (TIE) x_i as given by

$$x_i = n_i T_0 - t_i = \frac{\theta(t_i)}{\omega_0}. \tag{5}$$

As shown in Figure 12, (a) indicates the standard frequency signal, (b) shows the telecom data signal, and (c) illustrates the corresponding value n_i at the trigger instant t_i. Without loss of generality, we replace the sinusoidal wave by the square wave in this figure. Moreover, one can find that the time interval between the measured data, $t_{i+1} - t_i$, is not constant in this example. However, since in most of the synchronization measurements the sampling rate of TIC is usually much smaller than the network data rate, the measured TIE samples can only be slightly unevenly spaced. Hence, the computation results can still be reliable, according to the verification of the previous section.

CONCLUSIONS

In this paper, we have investigated the MTIE and TDEV performance for evenly and unevenly spaced data. Among all results of the simulated phase noise data, one can observe that the performance difference between the evenly and the slightly unevenly spaced data is almost negligible for most of the cases. The results convince us that when we conduct the telecommunications synchronization measurement, the computed MTIE and TDEV performance by using the formulas defined in ITU-T specification can still be correct and reliable even though the measured data are not evenly spaced. Based on the above results, we proposed a novel architecture for telecommunications synchronization measurement. In the proposed scheme, we omit the hardware clock recovery circuit interface in the conventional measurement system. And the digital data signal can be input to the time interval counter directly for phase comparison with the reference timing signal. Therefore, the cost of the measurement equipment is reduced and the convenience of the measurement is enhanced.

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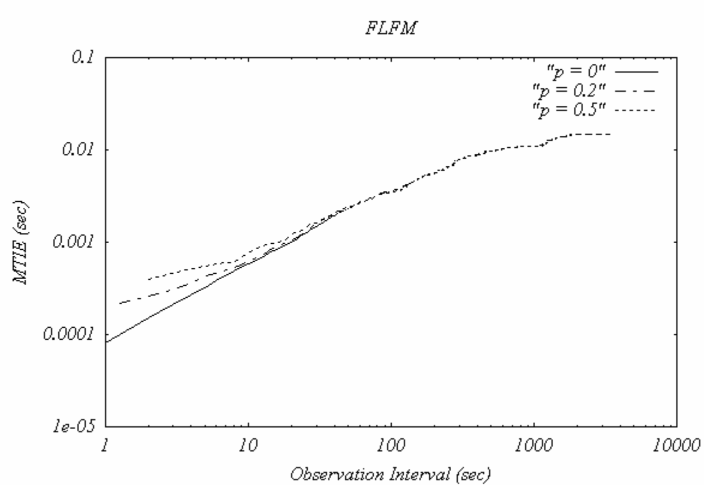

Figure 1. The results of MTIE obtained from simulated FLFM data.

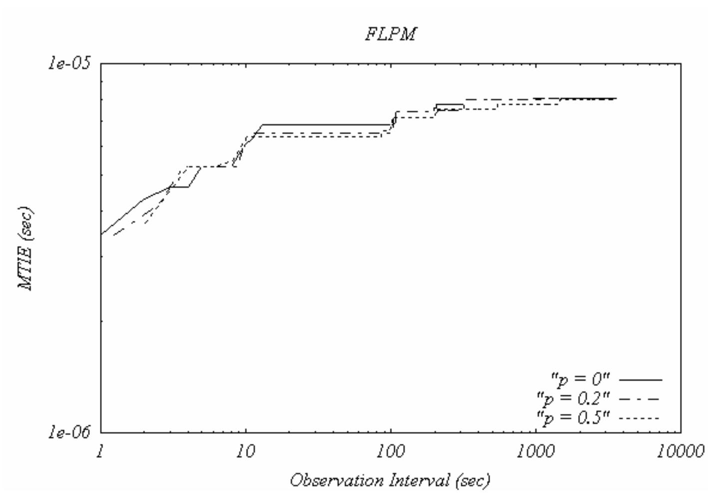

Figure 2. The results of MTIE obtained from simulated FLPM data.

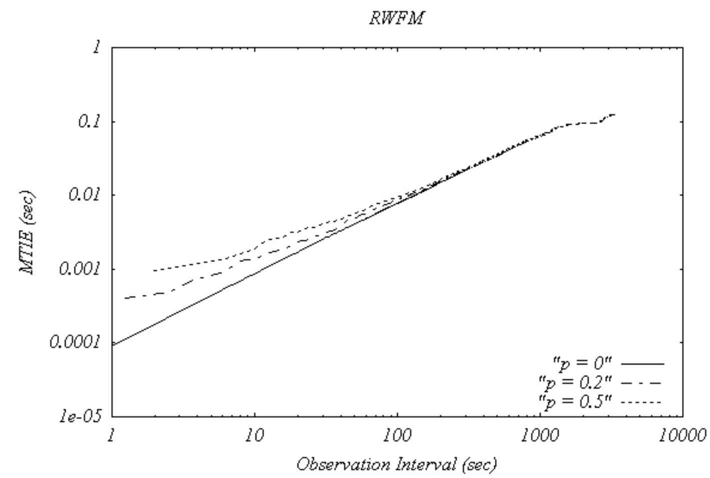

Figure 3. The results of MTIE obtained from simulated RWFM data.

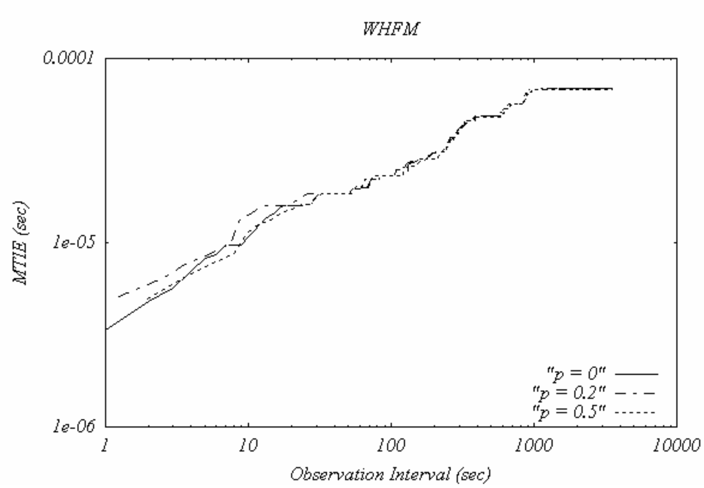

Figure 4. The results of MTIE obtained from simulated WHFM data.

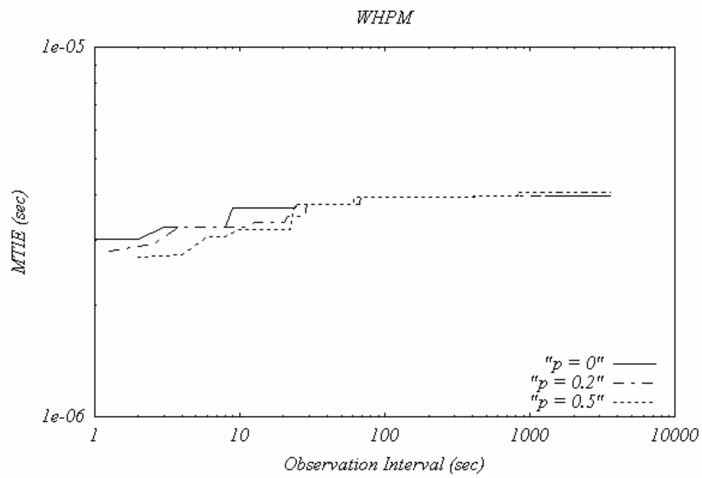

Figure 5. The results of MTIE obtained from simulated WHPM data.

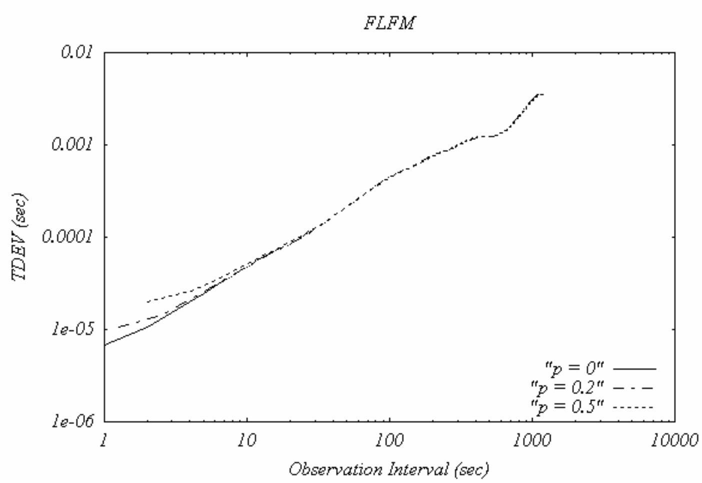

Figure 6. The results of TDEV obtained from simulated FLFM data.

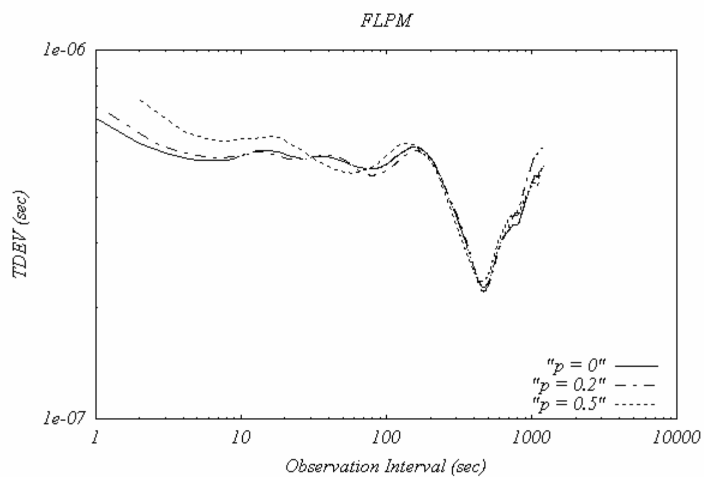

Figure 7. The results of TDEV obtained from simulated FLPM data.

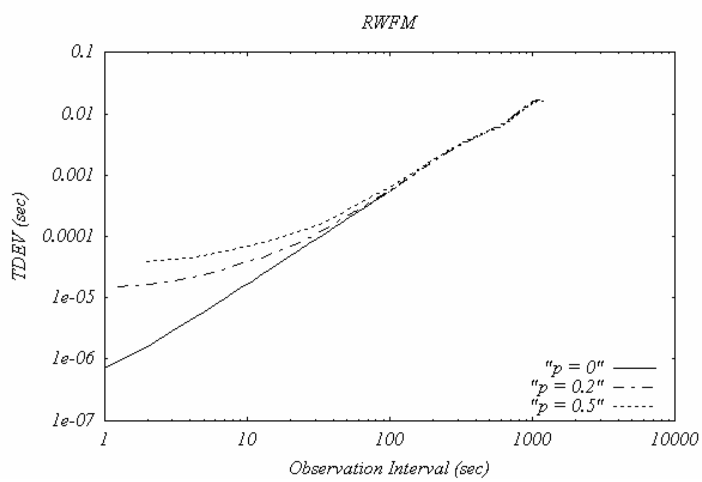

Figure 8. The results of TDEV obtained from simulated RWFM data.

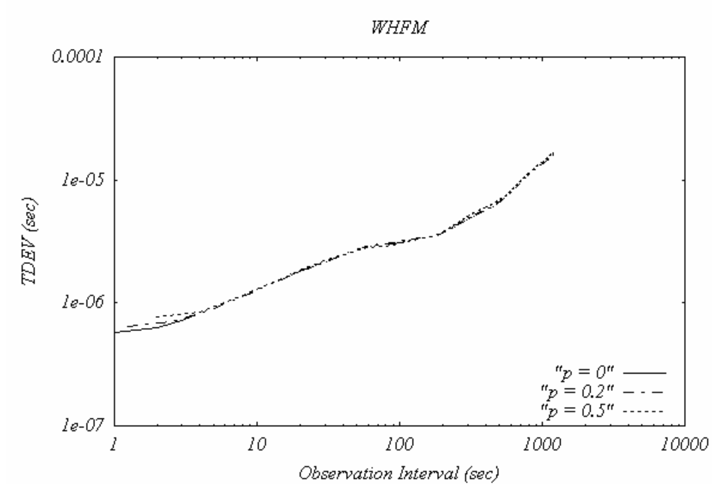

Figure 9. The results of TDEV obtained from simulated WHFM data.

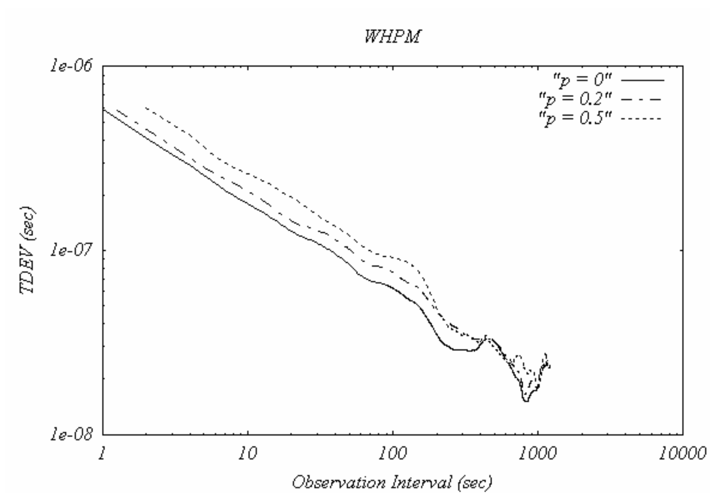

Figure 10. The results of TDEV obtained from simulated WHPM data.

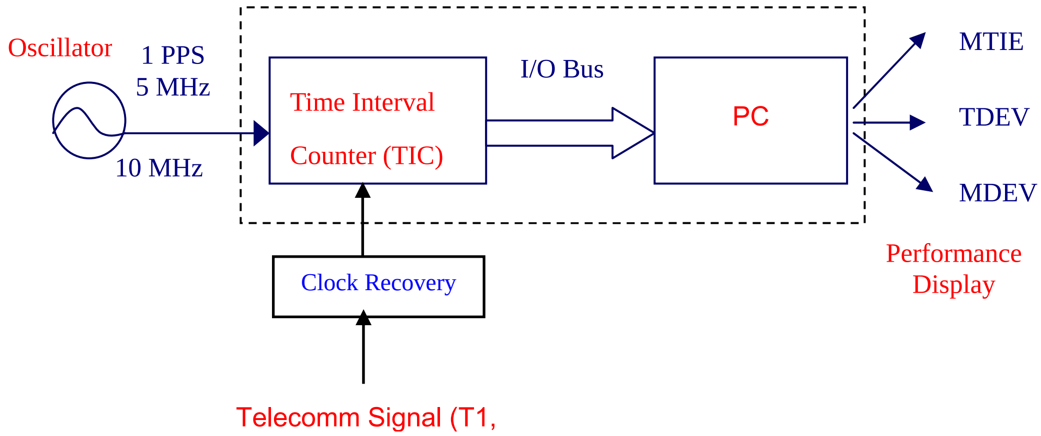

Figure 11. The conventional block diagram for synchronization measurements.

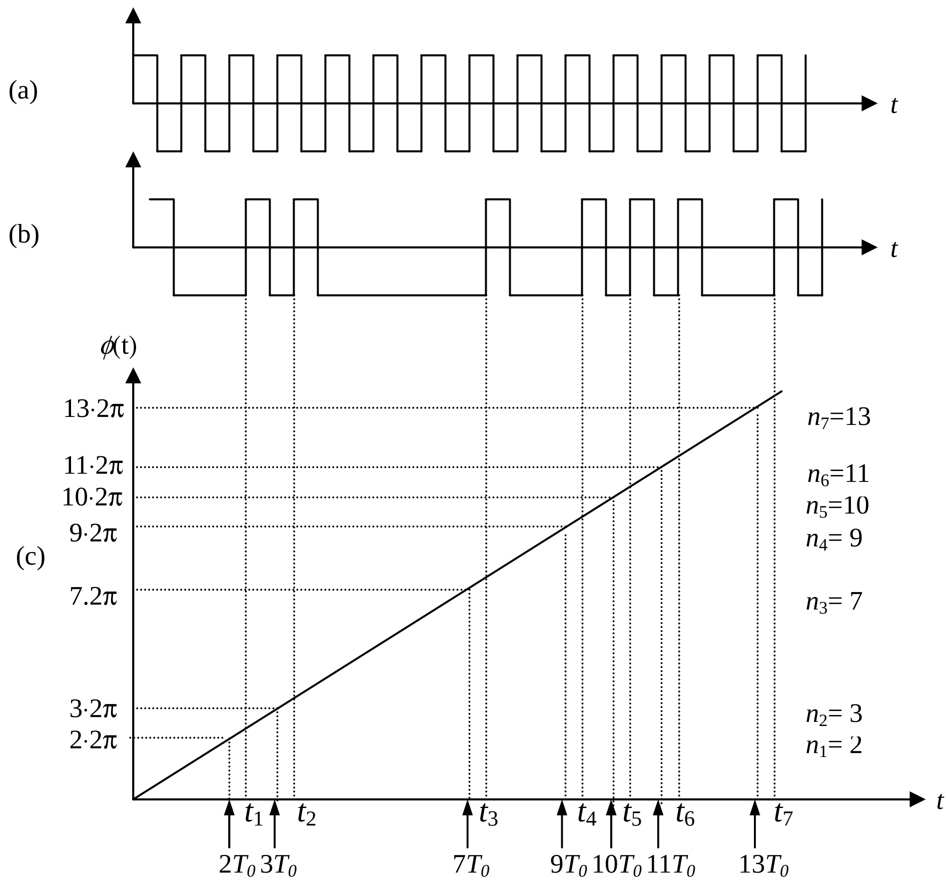

Figure 12. The illustration of phase comparison between the timing signal and the data signal.